CORPS OF ENGINEERS, U. S. ARMY

EFFECT OF ELECTRIC CURRENT ON THERMISTOR TEMPERATURE ERROR

by

W. M. Rohsenow and John Stekly

Contract No. DA-19-016-ENG-4010

TECHNICAL REPORT NO. 71

Under Contract With

Arctic Construction and Frost Effects Laboratory
U. S. Army Engineer Division, New England
Waltham, Mass.

for

Office of the Chief of Engineers
Airfields Branch
Engineering Division
Military Construction

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PREFACE

This report presents the results of a study, conducted at the Massachusetts Institute of Technology during the period 1 July 1955 and 30 June 1956, representing one phase of the theoretical and experimental study of ground and air temperature measuring methods performed by Professors Warren M. Rohsenow and John A. Clark, under Contract No. DA-19-016-ENG-4010 with the Arctic Construction and Frost Effects Laboratory of the U. S. Army Engineer Division, New England, Waltham, Massachusetts. These studies are being conducted for the Office, Chief of Engineers, Department of the Army, Airfields Branch, Engineering Division, Military Construction, as a continuing program for the development and evaluation of design criteria for construction in arctic and subarctic regions and areas of seasonal frost.

SYNOPSIS

Thermistors used as temperature sensing devices develop internal heat by the passage of electrical current during measurements. A theoretical analysis of effect of internal heat generation is applied to one type of thermistor. Calculations of steady-state temperature rise over the ambient indicate that the magnitude of error for the thermistor located in soil, ice, light snow, medium snow, and heavy snow ranged from 6.5×10^{-5} to 246×10^{-5} °F. while the magnitude of error for the thermistor located in air ranged from 712×10^{-5} to 1425×10^{-5} °F., depending on the heat transfer coefficient. Calculations indicate that in most cases errors due to internal heating may be disregarded for ground and air temperature measurements.

NOTATIONS

c_p	Specific heat at constant pressure, BTU/lb - °F.
E	Voltage, volts
h	Heat transfer coefficient, BTU/hr-ft^2 - °F.
I	Electric current, amperes
k	Thermal conductivity, BTU/hr-ft - °F.
ℓ	An energy quantity per unit volume, defined as product of density, specific heat at constant pressure, and absolute temperature, BTU/ft^3
q	Rate of heat flow, BTU/hr
R	Electrical resistance, ohms
r	Radial distance (radius), ft
T	Temperature, °F.
y	Reduction factor of temperature amplitude (no units)
α	Thermal diffusivity, ft^2/hr
ρ	Density, lb/ft^3
τ	Time, hours

EFFECT OF ELECTRIC CURRENT ON THERMISTOR TEMPERATURE ERROR

1-01. This report is a study of the error in measured temperature when a thermistor is used as the temperature measuring device.

1-02. The thermistor is an electrical resistance which changes rapidly with temperature. Consequently, if the resistance-temperature curve for the thermistor is known, it can be used as a temperature measuring device. However, to measure the resistance a finite amount of current has to be passed through the thermistor. This current in turn generates an I^2R electrical loss in the thermistor itself. This heat generated must be transferred away from the thermistor. The higher the resistance to heat transfer, the higher the temperature rise of the thermistor above the ambient temperature. From the above, we see that it is desirable to have a low current, and a low resistance to heat transfer for accurate temperature measurements.

1-03. Since most thermistors are small, it is reasonable to assume that they will behave very much like a sphere with internal heat generation.

1-04. For a sphere in a conductive medium (no convection or radiation) Jakob* develops the following formulas for the temperature rise of a sphere with internal heat generation above the surrounding temperature:

Transient:

$$\Delta T = \frac{q}{4\pi^{3/2}\, r^2 \rho\, c_p \sqrt{\alpha}} \int_{1/\sqrt{\tau}}^{\infty} \frac{1}{y^2} \left[1 - \ell^{-\frac{r^2 y^2}{\alpha}} \right] dy \qquad (1)$$

where

$$y = \frac{1}{\sqrt{\tau - \tau'}}$$

which reduces to the following for $\tau \longrightarrow \infty$ or steady state:

$$\Delta T = \frac{q}{4\pi\, kr} \qquad (2)$$

---

*M. Jakob, Heat Transfer (John Wiley & Sons, Inc., New York), vol. I, p 340.

1-05. For a sphere in a convective medium (no radiation), Clark and Kobayashi* derive the following equation for a sphere:

$$\Delta T = \frac{q}{4\pi\ hr^2}\left(1 - \ell^{-\frac{3h\tau}{\rho\, c_p\, r}}\right) \tag{3}$$

which reduces to

$$\Delta T = \frac{q}{4\pi\ hr^2} \tag{4}$$

at

$$\tau \longrightarrow \infty$$

1-06. Let us now consider an actual thermistor:

17A thermistor
Type: disc
Resistance: 3400 ohms at 0°C., 1000 ohms at 25°C.
Diameter: 0.2 in. (r = 0.1 in.).

If the ratio resistor in the bridge circuit is 10,000 ohms and the bridge voltage is 1.5 volts, then the current through the thermistor may be calculated at the ice point:

$$I = \frac{E}{R} = \frac{1.5}{10{,}000 + 3{,}400} = 1.12 \times 10^{-4} \text{ amps}$$

The electrical loss in the thermistor is then:

$$\begin{aligned} I^2R = (1.12 \times 10^{-4})^2 \times 3400 &= 4.25 \times 10^{-5} \text{ watts} \\ &= 1.245 \times 10^{-5} \text{ Btu/hr} \end{aligned}$$

1-07. For a 17A thermistor in the ground, the steady-state temperature rise of the thermistor above the ground temperature is calculated from equation 2 and presented in the following table:

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*J. A. Clark, and Y. Kobayashi, The Properties of Thermistors, report to U. S. Army Corps of Engineers, 1957, under Contract No. DA-19-016-ENG-4010.

	k, Btu/hr ft °F.	T, °F.
Soil	1.83	.000065
Ice	1.33	.0000895
Light snow	0.0483	.00246
Heavy snow	0.242	.000491
Medium snow	0.094	.00127

The values of thermal conductivity for this table were obtained from An Analysis of Errors in Ground and Air Temperature Measurements by W. M. Rohsenow, J. A. Clark, P. C. Van Alstyne, report to Arctic Construction and Frost Effects Laboratory, New England Division, Boston, Mass., for Office of the Chief of Engineers, Airfields Branch, Engineering Division, Military Construction, October 1954.

1-08. For a thermistor in air, the steady-state rise in temperature or error is calculated from equation 4, and is a function of the heat transfer coefficient, h, between the thermistor surface and the air. The magnitude of h due to radiation and convection combined will probably not be less than 1.0 and often will be greater than 2.0. The thermistor error for these magnitudes of h is as follows:

	h, Btu/hr ft^2 °F.	T, °F.
Air	1.0	.01425
Air	2.0	.00712

Equations 1 and 3 may be used to calculate the transient error. Actually, the errors calculated above will seldom be realized because the electric current for taking readings will not be flowing continuously--just long enough to get a reading.

1-09. The values given above are all extremely small, so that no detectable error due to electrical heat generation in the thermistor is expected. Since the errors are all small, no calculation for the transient-state errors has been made.

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1. Thermistors--Temperature measurements
2. Soils--Temperature penetration
3. Ice and snow--Temperatures

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